

**DEVELOPMENT OF A ROTARY JOINT FLUID COUPLING
FOR
SPACE STATION FREEDOM**

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ABSTRACT

This paper describes the design and development of a rotary joint fluid coupling for Space Station Freedom. The function of this fluid coupling is to transfer a heat rejection fluid between stationary and rotating interfaces within the Space Station thermal bus system. The design of this coupling incorporates a modular type design to allow maximum flexibility, two types of seals (mechanical face seals and shaft lip seals) for redundancy, materials with excellent ammonia compatibility, and coatings that enhance seal wear resistance and increased protection against corrosion. This design has been thoroughly tested and has met all design requirements. Potential applications of this hardware include uses in gun turrets, coal slurries, farming equipment, and any other applications that require the low leakage transfer of fluids between stationary and rotating interfaces.

INTRODUCTION

The Space Station Freedom, as currently envisioned, will be gravity gradient stabilized and incorporate rotating solar arrays and thermal radiator panels. The rotation of the solar arrays and radiators, to track the sun and deep space respectively, will allow for a more efficient thermal and power system with a reduced overall size, weight, and cost.

This rotation requirement calls for the development of structural, fluid, and electrical mechanisms to provide for the transfer of loads, thermal fluids, and power across the rotating interfaces. As part of the Space Station Freedom advanced development effort, a R&D effort was begun at LaRC to generate a design of a rotary joint fluid coupling to transfer thermal fluids across a rotating interface within the Space Station Freedom thermal bus system.

The objectives of this advanced development program were to demonstrate the feasibility of rotary joints and to evaluate the design concepts proposed for 360° continuous rotation. These objectives included the identification of manufacturing and assembly methods, identification of candidate materials with ammonia compatibility, selection of seals, determination of leakrates, determination of drive power requirements, and lifetime assessment. From these objectives in conjunction with the performance requirements and the expected mission of the Space Station Freedom a set of design requirements were generated. These design requirements are as follows:

- 360° rotation capability
- 20 years of continuous rotation with little or no maintenance (100k revs.)
- .01 RPM rotation rate
- Anhydrous Ammonia compatible
- Flowrates based on 300 KW thermal load
- Leakrate less than .018 scc/sec (454 g/yr)
- 3 flow circuits (gas and liquid passages = 1 flow circuit)
- Less than 1.0 psi pressure drop per flow circuit
- Low drive torque

Three single circuit conceptual designs for rotary fluid couplings were investigated. An engineering model for each concept was designed and fabricated. Testing of each unit was then conducted in an ammonia flow testing facility which simulated the Space Station Freedom thermal bus. Based upon the results of the testing, an engineering prototype unit or Life Test Article (LTA), (see figure 1), was designed, fabricated, and successfully tested.

LTA ROTARY FLUID COUPLING DESIGN

A modular, systems type approach was utilized in the LTA design to seal the flowing ammonia. Mechanical face seals served as primary seals to isolate the flowing ammonia from the secondary rotary shaft lip seals (see figure 2). To accommodate the modular approach to sealing the ammonia, the LTA exterior housing was designed as segmented units. Segmenting the housing of the LTA provided the capability for both portions of the mechanical face seals and rotary shaft lip seals to be installed into the housing segments before assembly onto the shaft. Flexibility to increase the number of circuits was obtained by just adding additional segments. The housing segments were machined out of 6061-T6 aluminum alloy, and were sulfuric acid anodized which provided protection from the corrosive environment. Vapor and liquid flow annular passages were machined into the exterior housing segments. These passages were sized to provide for a larger hydraulic diameter which in turn decreased the pressure drop of the LTA. In addition to these passages, leak ports were machined into the housing segments in order to measure the leak rates of the primary and secondary seals. The outer two leak ports served as both leak ports and as scavenger ports to scavenge off any potential exterior leakage. The nonsegmented shaft which the exterior housing assemblies mount to was also machined out of 6061-T6 aluminum alloy. Vertical and horizontal flow passages were machined into the shaft. The shaft was coated with a General Magnaplate HCR coating, an anodized and teflon impregnated coating, which provided a hard, smooth, and low coefficient of friction surface for the seals to wear against. The outer diameter of the shaft was 3.0 inches. This provided enough space to accommodate all vapor and liquid flow passages, and allow for the use of standard, commercially available seal types and sizes.

The mechanical face seals incorporated 7 major elements (see figure 3). The metallic elements (spring, torque nut, and shell) were made of a 300 series stainless steel. The rotor (seal ring) was made of grade P8290 carbon graphite. The stator (housing seal) were made of grade PS9242 reaction bonded silicon carbide. The rotor and stator were lapped to a flatness of 1-3 Helium light bands. The diaphragm and o-ring seal on the stator were both fabricated of ethylene propylene.

Rotary shaft seals were used as secondary and backup seals in the LTA design. Ultrahigh Molecular Weight Polyethylene and 316 stainless steel were selected for the jacket and spring material of the rotary shaft seals (see figure 4). These seals provided redundant sealing capability for any leakage through the mechanical face seals. These seals also prevented the elastomeric components of the mechanical face seals from being exposed to the hard vacuum of a space environment.

ROTARY FLUID COUPLING TESTING

An ammonia flow test facility was designed and built to provide the range of flow and rotation rates required to simulate the Space Station Freedom thermal bus system. This system (see figure 5), was designed primarily to operate with liquid anhydrous ammonia. Flow rates from 0 to 2.65 gpm could be selected. A drive system provided rotation rates through the drive shaft from .01 to 1.00 rpm, with an output torque of 492 ft-lbs available over the entire range. The operating temperature of the system could be controlled from -35°F to 90°F using a separate temperature controlled liquid bath and heat exchanger.

The LTA was installed and tested in the ammonia flow facility. The pressure within the test facility flow circuit was maintained between 114 psig and 126 psig. This was controlled by maintaining the system temperature between 70 - 75°F. The rotation rate of the LTA was set at 1.0 rpm for the majority of the testing. This rate was somewhat arbitrary; however, the objective was to accelerate the test without modifying the performance of the seals. To obtain data at actual Space Station Freedom rotation rates, the drive speed was occasionally lowered to .01 rpm.

The LTA life testing performance parameters that were measured from this testing are as follows:

- Breakout torque
- Running torque at .01 & 1.0 RPM
- Flow circuit pressure drops
- Primary seal leakage at .01 & 1.0 RPM
- Secondary seal leakage at .01 & 1.0 RPM

- Exterior coupling leakage at .01 & 1.0 RPM
- Number of revolutions

The breakout and running torques were measured by strain gages mounted on the input drive shaft to the LTA. The drive torque produced by the LTA at .01 and 1.0 rpm was recorded on a strip chart throughout the life test.

The pressure drop through the flow circuit of the LTA was measured by a differential pressure transducer mounted between the inlet and outlet flow ports of the coupling. The pressure drop through the coupling was monitored and recorded continuously in order to determine the effect of shaft flow port position vs housing flow port position.

The primary and secondary seal leakages were measured by detecting the pH change in a controlled volume of a standard liquid after the liquid has combined with the ammonia that has leaked past the seals. Dry nitrogen gas was flowed through the primary and secondary seal leakports (see figure 6) in order to purge the ammonia into a tank containing the reference solution. The ammonia was then absorbed into the solution and the pH change is noted for that given time period. This solution was then titrated back to the reference pH value with a known amount of acid. Knowing the amount and type of acid required to titrate the solution back to the reference pH value, and the duration of the data period the seal leakage was calculated.

Exterior leakages from the end caps (Drive side and Loop side) of the LTA (see figure 6) were also derived in the same manner as the seal leakages. These leakages represent the leakage that would escape from the coupling or could be contained in some form of a scavenger system for on-orbit operations..

ANALYSIS OF TEST RESULTS

The LTA initial breakout torque was approximately 44 ft-lbs. After the initial breakout, the torque dropped to a level of 25 ft-lbs. As the seals proceeded to seat, the drive torque steadily increased to a maximum of 52 ft-lbs at 10,000 revs. Once the seals were seated, the torque began to steadily drop to a running torque level of 36 ft-lbs. This running torque level was observed for the remainder of the test (200,000 revs.) . No significant change in drive torque was observed when the rotation rate was lowered to .01 rpm. (see figure 7)

The LTA end cap leakage was the amount of ammonia that leaked past the end seals on either side of the coupling. The drive end cap leakrates ranged from 8×10^{-3} to 1×10^{-3} scc/sec at 1.0 rpm and 5×10^{-3} to 1×10^{-3} scc/sec at .01 rpm. The LTA loop end cap leakrates were in the same range as the drive end side.

The secondary seal port leakage was the amount of leakage that leaked past the secondary rotary shaft lip seals. The secondary seal leakage ranged from 4×10^{-2} to 1×10^{-3} scc/sec. The primary seal port leakage was the amount of fluid that leaked past the primary mechanical face seals. The primary seal leakage ranged from 4×10^{-2} to 1×10^{-2} scc/sec.

Pressure drop through the coupling was measured and recorded on the facility data acquisition systems. The data showed pressure drops from .35 to .50 psid. This variation in pressure drop depended on the orientation of the shaft flow port relative to the flow port in the exterior housing. The pressure drop was cyclical with each revolution of the shaft.

CONCLUSION

The LTA met all performance requirements for a 20 year equivalent life test (100,000 revolutions). This coupling was actually tested to twice the expected mission life (40 yrs. or 200,000 revs.). Primary seal leakrates for the coupling were in the 10^{-2} scc/sec range and secondary seal leakrates were in the 10^{-3} scc/sec range. Running

torque for the coupling was 35 - 37 ft-lbs, and breakout torque was approximately 45 ft-lbs.

With slight modifications to the baseline design, the exterior (scavenger port) leakage can be reduced further to the 10^{-4} scc/sec (.01 lbm/yr) range. This modification would entail the addition of 2 rotary shaft seals located on either end of the coupling. These additional seals will increase the drive torque slightly, but will drastically reduce the size of the ammonia scavenger system.

The versatility of this rotary fluid coupling design will allow for its use in a variety of applications. This design can easily be modified to accommodate different shaft and housing materials, a variety of flow circuit configurations, pressures, and temperature ranges.

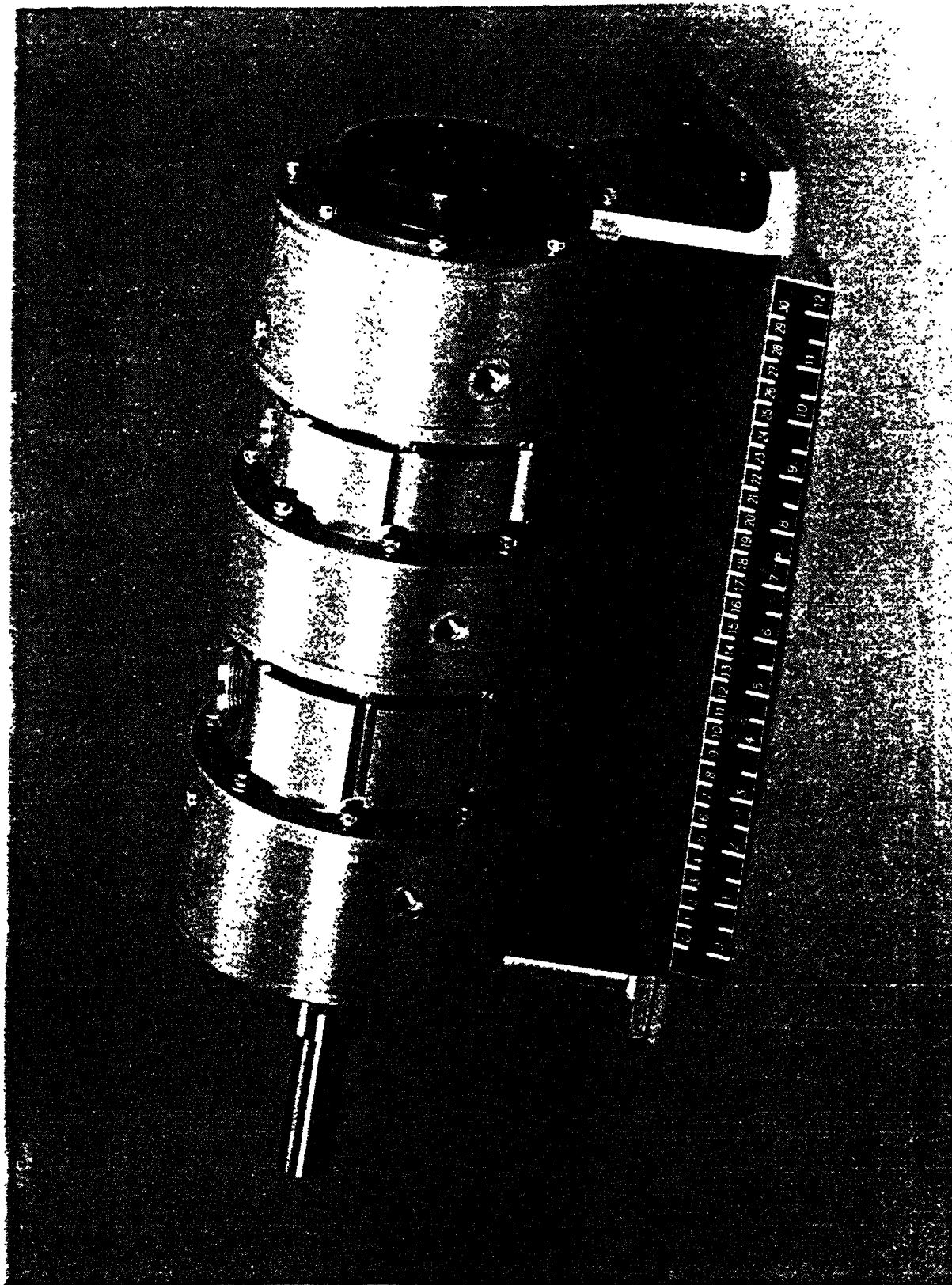


FIGURE 1: LIFE TEST ARTICLE

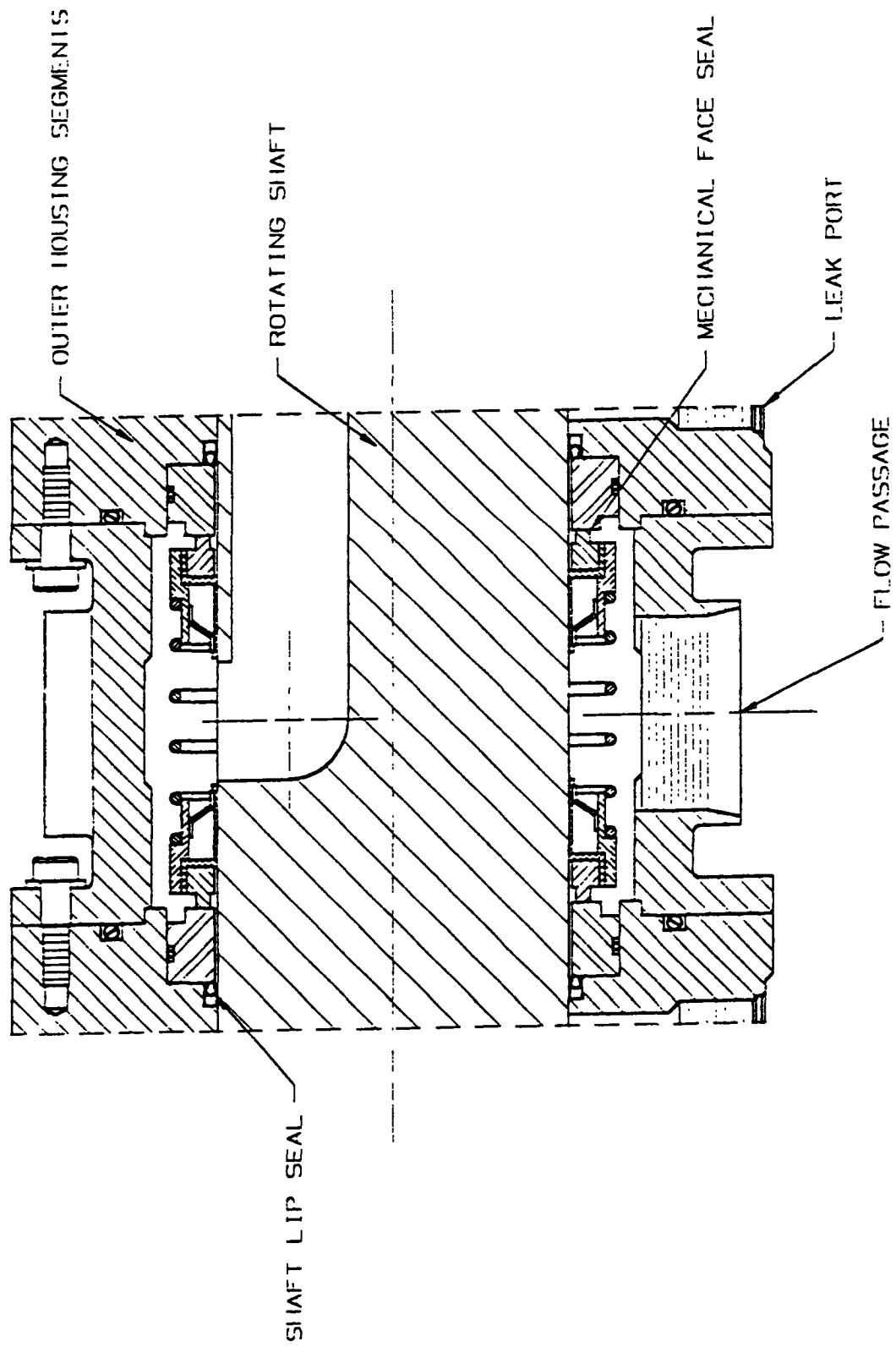


FIGURE 2: TYPICAL SEAL ASSEMBLY

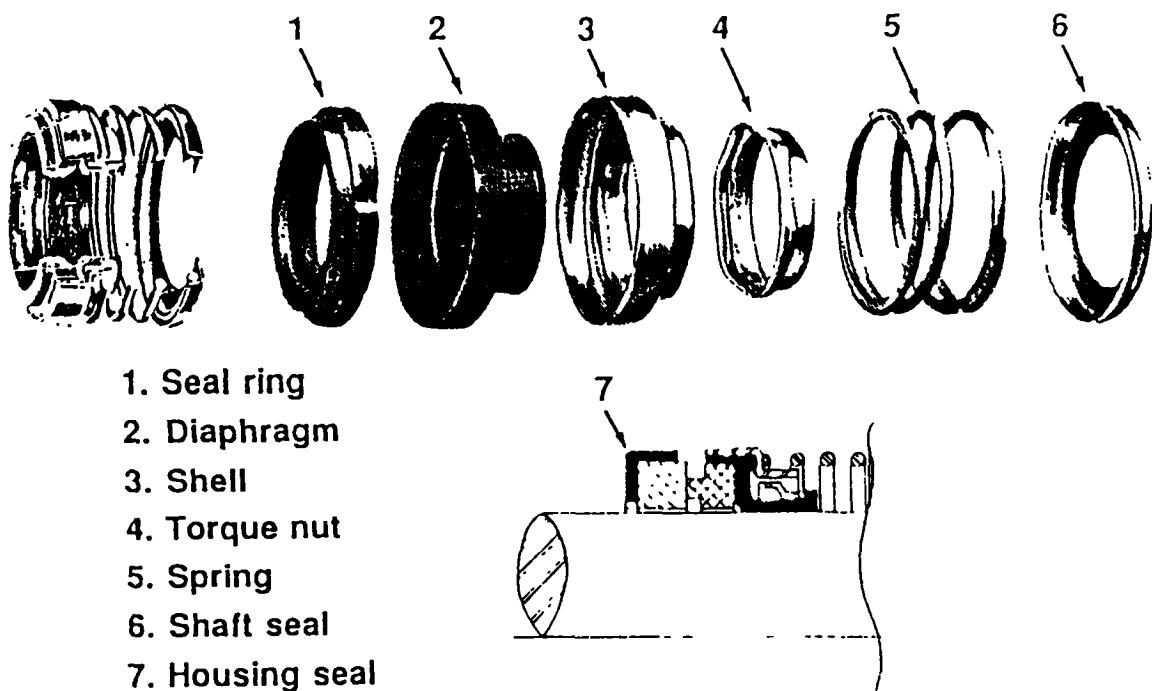


FIGURE 3: MECHANICAL FACE SEAL ASSEMBLY

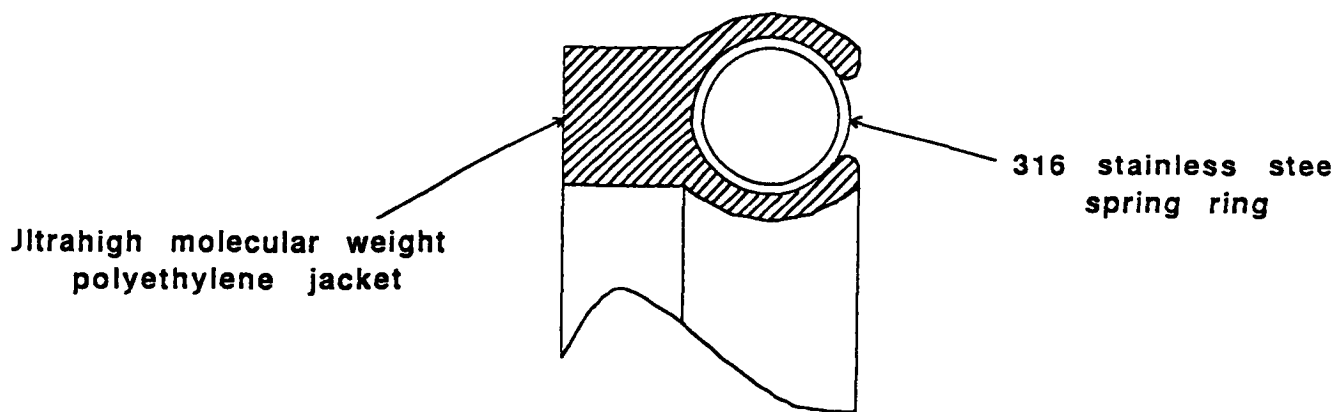


FIGURE 4: ROTARY SHAFT LIP SEAL

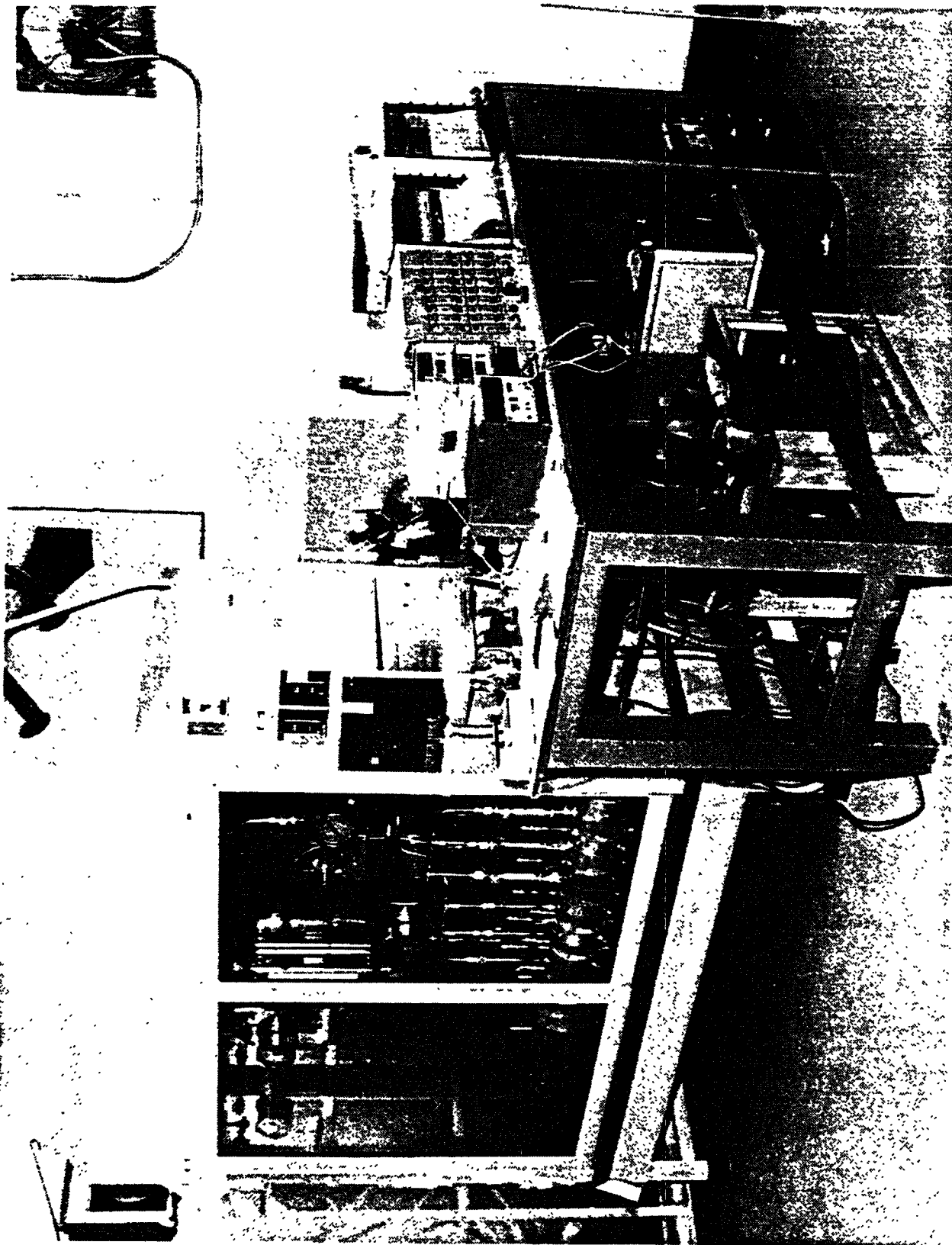


FIGURE 5: ROTARY JOINT TEST FACILITY

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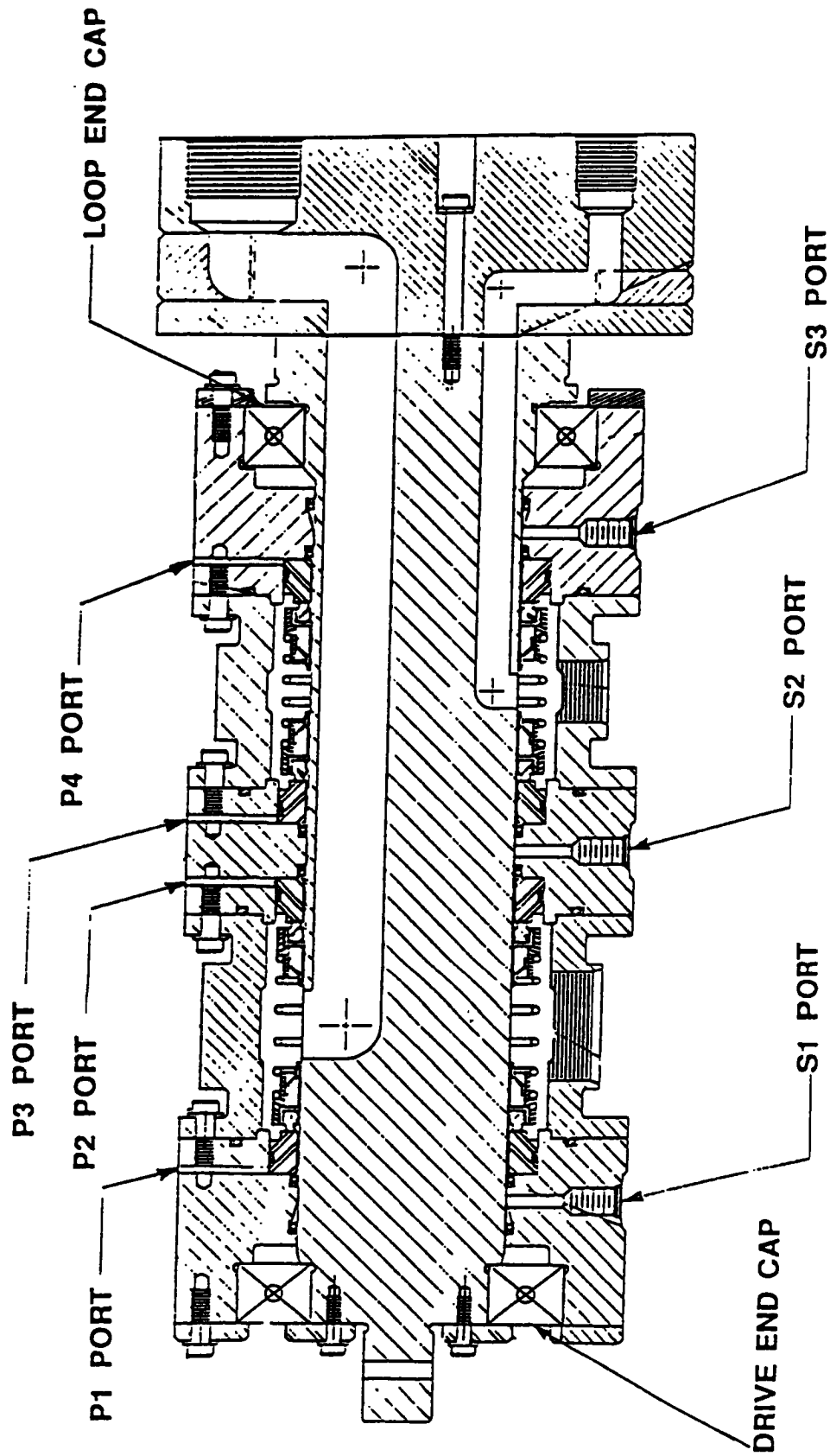


FIGURE 6: LTA LEAK PORTS

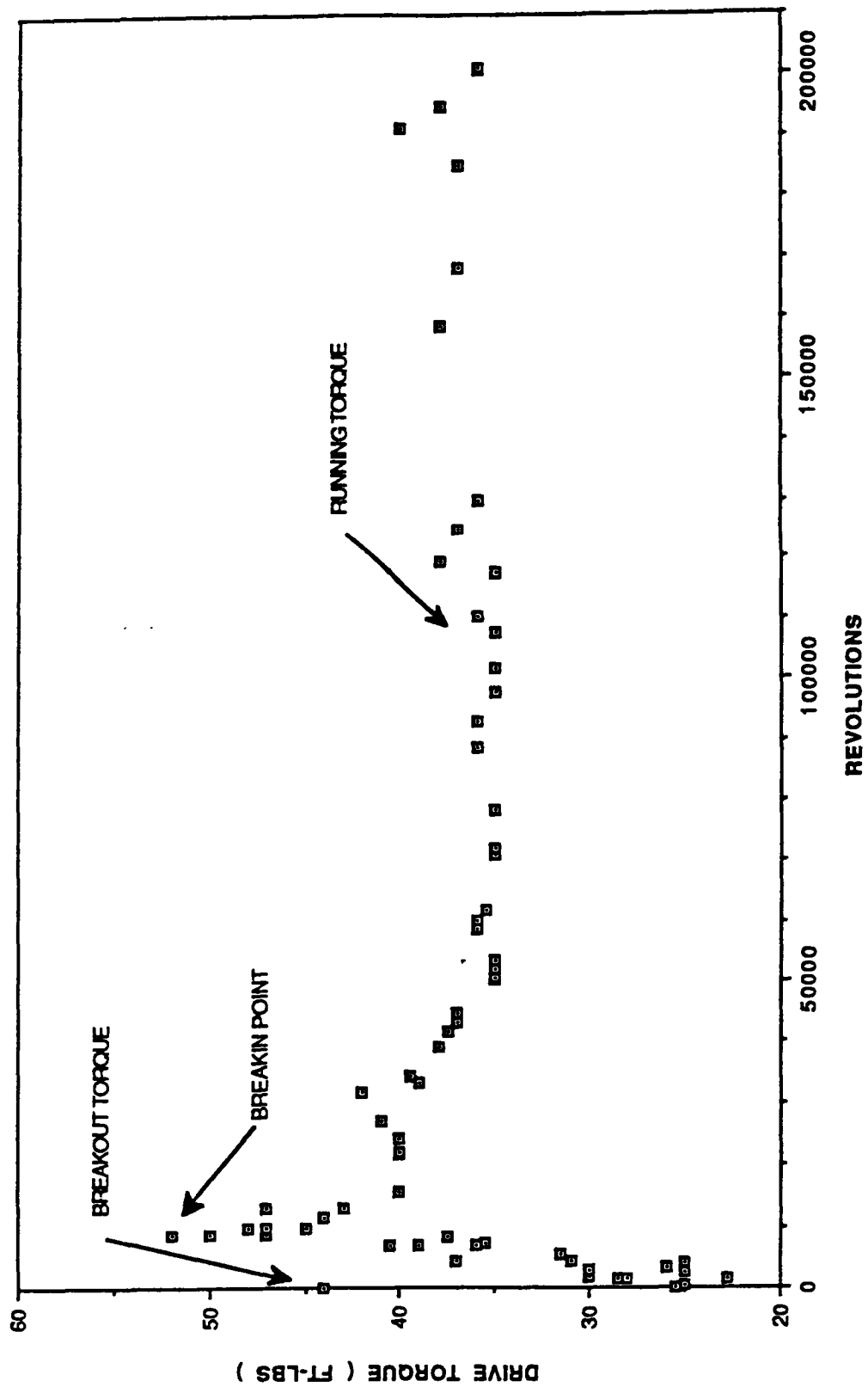


FIGURE 7: LTA DRIVE TORQUE